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Cincinnati, Ohio

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Robert Porter

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A NEW TECHNIQUE FOR FABRIC FILTER EVALUATION

by

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INTRODUCTION

Research on air filtration been conducted in the past primarily with bench-scale equipment. Collection efficiencies, aerosol deposition mechanisms, and fluid flow through porous media can be and have been studied in this way. Research on full- or pilot-sized air filtration equipment has been restricted, however, by a lack of adequate techniques for measuring filtration and fluid flow parameters in such units.

Information about rates of dust cake buildup and about filter velocities at specific locations on a filter surface would make possible a more detailed understanding of the filtration process as it occurs in practice. From a series of measurements at selected locations on the surface of a filter, profiles could be plotted which would relate the mass of the dust cake and the filter velocity to position on the filter and which would demonstrate changes in these values with time through the progress of a filtration cycle. Information of this type would give insight into the actual operation of commercial-sized air filters and

would provide important keys for the establishment of optimum design and operational standards.

For the purpose of implementing this new technique for fabric filter evaluation, two new instruments have been developed in the Air Pollution Engineering Laboratories of the Public Health Service. One of these, the "mass probe", allows determination of local filter cake masses and the other, the "filter velocity probe", allows concurrent determination of filter velocities through specific areas of a filter. While these instruments have been developed for laboratory use on full-sized tubular filter bags, they are certainly useable in the field and are adaptable for use with other types of air filtration equipment.

THE MASS PROBE

In the last decade a new engineering tool has become available, primarily as a quality control device for many industrial operations. This tool, the so-called beta thickness gauge, has found widely publicized application on production lines, but its use as a research tool has not been so widespread. The beta thickness gauge (the name "thickness gauge" is actually a misnomer) operates on the principle that beta radiation is absorbed by matter; therefore the intensity of radiation passing through an object is a measure of the mass of that object. Such an instrument, applied to the determination of the mass of a filter cake, has several advantages: the principle of operation is relatively simple, it is potentially quite accurate, it is, and perhaps this is the most important, able to make a measurement without physical contact with the material being measured, and it is readily adaptable to field use.

Isotope Selection

The choice of a radioactive source for such a probe involves a compromise among several desired properties. Ideally the source would 1) have high penetrating power, 2) have high sensitivity (large change in transmitted radiation for a small change in absorber mass), 3) have a constant intensity (long half-life), 4) have no gamma radiation content, 5) be safe to use, 6) be cheap and readily obtainable, and 7) be available in a convenient physical form.

A table listing beta-emitters by energy and half-life is presented in the Radiological Health Handbook[1]. Isotopes were successively eliminated from this list of possible sources by first establishing a minimum practical half-life of 150 days and a minimum beta energy of 0.3 Mev. The list of isotopes remaining was further narrowed to those given in Table I by applying the criterion of commercial availability.

Unfortunately, penetrating power (range) and sensitivity bear an inverse relationship to one another, thus dictating that an isotope having the lowest possible, but still adequate, range be chosen. From preliminary investigations it was learned that the maximum wall density encountered in the tubular bag filters to be studied will be on the order of 8000 grains/ft^2 (1 grain/ft^2 = 0.070 mg/cm^2), but that most measurements will fall in the region below 2000 grains/ft^2. Because of the tubular configuration of the filters, however, penetration of the beta particles must be through a double layer of dust cake plus an air space. It is also necessary that even at the greatest wall density an appreciable amount of radiation penetrate the object to be measured. To

assure this, the maximum penetration of the isotopes's beta particles should exceed twice the maximum wall density to be measured by roughly 50 percent. On this basis, it immediately becomes evident from the maximum penetration values listed in Table I, that Pb^{210}-Bi^{210} is the logical choice for measurements of wall densities of 2000 grains/ft^2 and less, and that Ru^{106}-Rh^{106}, in spite of its gamma content and relatively short half-life, can be used for filter loadings up to 8000 grains/ft^2. Because of its lower gamma content, Ce^{144}-Pr^{144} was considered as a possibility even though its range is slightly less than that desired, but the fact that Ru^{106}-Rh^{106} was immediately available as a sealed source while Ce^{144}-Pr^{144} could be supplied, on short notice, only in liquid solution clinched the final decision to use Ru^{106}-Rh^{106}.

Source Activity Required

Having established the particular isotopes to be used, it becomes necessary to determine the source intensity required of each. The factors affecting this decision are 1) the accuracy of measurement required, 2) the maximum allowable time for making the measurement, 3) the maximum count rate which can be metered by the available instruments, and 4) the physical spacing between source and pick-up tube. The levels chosen for each of these factors are as follows:

Required accuracy	±1% of wall density
Maximum time for measurement	30 seconds
Maximum count rate	300,000 counts/minute
Source-to-pick-up tube distance	9 inches

Since the decay of a radioactive element is a zero-order reaction which follows the laws of probability, a statistical analysis may be used to determine the accuracy with which a measurement may theoretically be made. It is known that, for a normal distribution, approximately 95 percent of all measurements will fall within $\pm 2\sigma$ (σ = standard deviation) of the mean; this 95 percent confidence level was arbitrarily accepted. From the statistics of radioactive counting, where, N = activity detected in cpm and t = counting time in minutes,

$$2\sigma = \pm 2\sqrt{\frac{N}{t}} \qquad [1]$$

At a 95 percent confidence level, to determine the air-gap count rate required to achieve a one percent accuracy in one-half minute, the change in mass associated with a 2σ change in activity detected must be determined over the entire calibration interval. For example, at the minimum mass to be measured, 800 grains/ft^2 (twice the approximate wall density of a clean filter fabric), a 2σ change in count rate must correspond to an 8 grains/ft^2 change in mass, i.e., one percent of the mass being measured. From equations for the theoretical calibration curves shown in Figure 1, it can be seen that for Pb^{210}-Bi^{210}, 2σ must be equal to 0.4 percent of the air-gap count rate. Expressing 2σ in equation [1] as a percentage at the air-gap count rate, N_o,

$$\frac{2\sigma}{N_o} \times 100 = \pm \frac{200}{N_o}\sqrt{\frac{N}{t}} = 0.4 \qquad [2]$$

Again using the equation for the theoretical calibration curve, N at 800 grains/ft^2 equals 0.4844 N_o. Hence, N_o must be 242,000 cpm. Repetitions of this procedure over the range of wall densities to be

measured show that, for the same theoretical accuracy, the largest air-gap count rate is required at the minimum wall density. Conversely, for a given source, percentage accuracy of measurement increases with increasing wall density. A similar calculation for Ru^{106}-Rh^{106} (at the minimum wall density to be measured with this source, 2000 grains/ft^2) indicates that an air-gap count rate of 341,000 cpm will be required. This count rate is above that which can be metered, but with a filter of 2000 grains/ft^2 wall density between source and pick-up tube, the maximum rate which must be counted is below 173,000 cpm.

Finally, it is necessary to ascertain the actual source activity required, taking into consideration the 9-inch spacing between source and pick-up tube. In general,

$$\text{Source activity} = \left(\frac{\text{Correction for}}{\text{air absorption}}\right)\left(\frac{\text{Correction for}}{\text{spacing}}\right)\left(\frac{\text{Required air-}}{\text{gap count rate}}\right)$$

The first factor to be considered is absorption of the air itself within the air gap. At an assumed density of 0.075 lbs/ft^3, the air gap has an areal density of 400 grains/ft^2. In the case of Pb^{210}-Bi^{210}, Figure 1 shows that this will necessitate a correction factor of 1.43; for Ru^{106}-Rh^{106} a correction factor of 1.04 is required. Secondly, because of the depletion of radiation flux with the square of the distance from the source, each square inch of surface nine inches from the source will receive only $\frac{1}{4\pi(9)^2} = \frac{1}{1018}$ of the emitted activity. Hence, when using a pick-up tube with a window area of 0.8 $in.^2$, the source activity must be,

$$Pb^{210}\text{-}Bi^{210} \text{ source activity} = (1.43)\left(\frac{1018}{0.8}\right)(242{,}000) \text{ cpm}$$

$$= 200 \text{ microcuries}$$

and,

$$Ru^{106}\text{-}Rh^{106} \text{ source activity} = (1.04)\left(\frac{1018}{0.8}\right)(341{,}000) \text{ cpm}$$

$$= 205 \text{ microcuries}$$

The cost of such sources is nominal; the Pb^{210}-Bi^{210} and Ru^{106}-Rh^{106} sources used were purchased for well under $100 each.

Probe Design

The first probe constructed, using a Pb^{210}-Bi^{210} source, is shown in Figure 2. The source, a disc 7/8-inch in diameter with appropriate shielding, is mounted in one end of a semi-circular Formica frame. A standard end-window GM tube is mounted diametrically opposite the source. Attached to the Formica frame directly above the GM tube is an aluminum support rod. An adjustable stop, installed in the Formica frame at 90 degrees to the axis of measurement, aids correct centering of the probe around the filter bag.

The Ru^{106}-Rh^{106} probe, Figure 3, is somewhat improved over its predecessor. As will be discussed later, probe calibration is sensitive to the positioning of the filter bag within the air gap. By mounting source and pick-up tube in separate holders and then joining them with one of a series of connectors, the possibility of variations in positioning is eliminated since source and GM tube are mounted as close together as clearance around the particular filter bag will allow. Further advantages of this type frame are 1) potential accuracy is increased for filters less

than 9 inches in diameter since count rate is increased by reduced air gaps, and 2) at the sacrifice of somewhat decreased accuracy, measurements may be made on filters with diameters exceeding 9 inches.

While the calculated activity for the Ru^{106}-Rh^{106} source was 205 microcuries, a larger source, 350 microcuries is actually used. The air-gap count rate is reduced to approximately the calculated level by the use of a flat brass absorber over the source. The thickness of this absorber is decreased at approximately one-month intervals to compensate for the decay of the source. The 350-microcurie source being used will produce adequate activity for approximately eleven months with no reduction in accuracy.

It should also be pointed out that each probe is equipped with a protective cap which is placed over the source when the probe is not in use to eliminate unnecessary radiation exposure to personnel. Also, each GM tube operates with a cathode follower to minimize high voltage requirements and extend tube life.

Scaler

The counter used is a Model 163 Nuclear Instrument and Chemical Corporation Scaler which has been modified[3] to produce automatic recording of detected activity on a standard millivolt recorder. This modification increases the maximum counting rate to 300,000 cpm by eliminating the mechanical register dial and permits the probe to be used by a single operator for a series of mass measurements in the shortest possible time.

Calibration

Unfortunately, because of scatter of beta radiation as it passes

through various materials, actual calibration curves for the mass probes differ significantly from the theoretical curves shown in Figure 1. The atomic mass of the absorbing atoms and the absorber geometry (the physical shape of objects between source and pick-up tube) can both contribute to these differences, but in most cases, beta absorption is roughly independent of the nature of the absorber[4]. It is therefore mandatory to calibrate such probes using the geometry that exists during measurements. The effect of geometry is shown rather dramatically in Figures 4 and 5, in the former the effect of flat vs. tubular absorbers and in the latter the effect of asymmetrical positioning of probe around filter bag. As was pointed out earlier, the improved design of the Ru^{106}-Rh^{106} probe minimizes the possibility of inadvertant positioning errors.

The specially designed calibration device used is shown in Figure 6. With this device, a 22-inch length of filter bag of the desired diameter is suspended from one pan of a double-pan balance. This bag is closed at the top and is sealed to the vertical inlet tube below with a thin polyethylene film. Dust is conveyed from the dust inlet chamber to the vertical inlet tube by a low volume, high velocity stream of compressed air. In the inlet tube it is mixed with a much larger volume of air supplied by a variable speed blower and the dust-air mixture passes upward into the calibration filter. Readings with the mass probe are then taken at a series of filter loadings, each loading being determined directly by in-place weighing of the suspended filter. Because of the existence of "mass profiles" on even this short calibrating filter, mass

probe readings are taken every four inches along the length of the filter and the results averaged to determine the exact wall density vs. recorder reading relationship. Readings obtained represent, of course, the average density of opposite walls of the filter; calibration curves shown in Figure 7, therefore, are in terms of this average density.

Because of the 22-year half-life of Pb^{210}-Bi^{210}, the intensity of this source may be considered constant for any experimental program of reasonable length; the much shorter half-life of Ru^{106}-Rh^{106}, however, causes the intensity of this source to diminish at a rate such that a compensation technique must be employed. As mentioned previously, the air-gap count rate is adjusted at one-month intervals by reducing the thickness of the flat absorber over the GM tube window. Day-to-day compensations, however, can be made with the combination scaler-recorder unit being employed. Since, as is evident from Figure 1, calibration data may be generalized in terms of <u>percent</u> of air-gap reading vs. wall density, calibrations are independent of source activity (within limits) and the same calibration curve, Figure 7b, may be used while the source intensity is decreasing. A variable resistor in the recorder circuit is used to change the number of counts represented by each chart scale division. Each day, before profiles are measured, a standard absorber is placed over the window of the GM tube. This absorber is known to have produced a chart reading of exactly 100 (scale factor = 64) at the time of calibration. The potentiometer is then adjusted to again give a 100 chart reading and the probe is ready for use. Every month, when

the absorber over the Ru^{106}-Rh^{106} source is replaced, the variable resistor is set back to its original position.

Use of the Probe

Using the mass probe, a series of mass readings on a tubular filter bag can be obtained with the present arrangement at the rate of 45 seconds per point. The sequence of events during a measurement cycle is 30 seconds for counting, 2 seconds for recording the count, and 13 seconds for repositioning the probe to the next sequential location. These timing intervals may, of course, be varied to meet specific test requirements. The results of a series of mass readings is a recorder strip chart containing a series of equally spaced lines, the height of each line being a measure of the wall density at a particular location on the bag.

Based upon a previously determined calibration, tabulations of dust mass measurements, in order along the length of a bag, are obtained by using a Benson-Lehner Semi-Automatic Chart Reader; these data may be subsequently shown graphically if desired.

Accuracy of the Probe

As indicated earlier, the accuracy with which a mass measurement may theoretically be made may be determined statistically from ideal calibration curves as are given in Figure 1. It will be remembered that accuracy theoretically increases with wall density. The same calculation techniques, when applied to the experimentally determined

calibration curves yield the relationships shown in Figure 8 between expected accuracy (i.e., counter reliability) and wall density. For Pb^{210}-Bi^{210} reliability does, in fact, follow the expected trend. For the Ru^{106}-Rh^{106} source, however, it is seen that accuracy is best at about 3000 grains/ft^2 and that accuracy gradually diminishes for wall densities above this value.

Certain systematic and personal errors are, of course, involved in the use of the probe, but it appears that these are less than the counting errors to be expected. For instance, chart reading error with the automatic chart reader should certainly be less than one-half percent of the full-scale deflection, and recorder reproducibility is of the same order. Counting errors caused by misalignment of the probe with the filter bag diameter are also less than one-half percent for displacements of the probe of up to 3/4-inch from the true bag diameter. It has also been shown that negligible error is introduced by "end effect", even when readings are taken as close as 1/4- to 1/2-inch to either end of a filter bag. The largest error arises undoubtedly in the calibration techniques used, but even here, the actual filter loadings should be known to within one percent.

THE FILTER VELOCITY PROBE

A knowledge of the actual filter velocities for the identical locations at which dust cake mass is known is also important. These two types of data, when evaluated in conjunction with pressure drop information, can indicate variations in cake porosity and thereby provide evidence

of different packing characteristics or different particle-size distributions over the extent of a filter surface.

An instrument for measuring local filter velocities must have two important properties: it must not affect the filter velocity while a measurement is being made, and it must be able to accurately measure very low velocities on the order of 1 to 10 ft/min. Considering the first of these properties, one may conclude that an extremely low pressure drop through the sensing element is required in order that the gas passing outward through the filter figuratively "does not know" that it is being metered, rather than passing directly to the outside.

Several types of sensing elements were considered, but the thermal anemometer appeared to be ideally suited for such service. Pressure drop through these devices can be made essentially zero, and accurate readings of air velocities as low as 5 ft/min may be obtained. In addition, thermal anemometers are rapid reading, quite convenient for use even in the field, relatively cheap, and their signal may be recorded.

In spite of the ability of the thermal anemometer to sense velocities on the order of 5 ft/min, this is still an order of magnitude greater than the lowest filter velocities which are encountered. Therefore, some type of probe head is required which will collect air from a given filter area and accelerate it to about ten times its original velocity for passage through the anemometer. A wide variety of probe heads were investigated ranging from very soft foam rubber cones, to thin-walled brass ones, to spring-mounted and foam rubber padded designs. The probe head to be used should 1) not disturb the dust cake within the

filter bag (i.e., not require the application of an appreciable force between probe and filter bag), 2) give reproducible readings even when operated by different observers, and 3) give satisfactory readings with both high and low pressure drops across the filter (i.e., for both clean bags and bags containing heavy dust cakes). In addition, it would be very convenient if the probe could be hand-held while readings are being taken.

Design of Probe

The probe-head design finally selected is shown in Figure 9. It consists of a rectangular cross-sectioned truncated pyramid to which a Hastings-Raydist thermal anemometer gauge tube is fastened. On the inlet end of the cone are two screen "wings" faced with a double layer of 1/2-inch foam rubber. In the center of the foam rubber pad is a rectangular hole through which the air "filtrate" passes into the pyramidal section and thence to the anemometer. This particular head design has been found to give reproducible readings and to require a minimum of pressure against the filter bag. As seen in Figure 10, the velocity reading obtained increases very rapidly as the probe approaches within 1/4-inch of the bag. As the probe just touches the bag surface, the indicated reading is within one or two percent of the maximum value which can be obtained.

Originally the velocity reading was made on an indicating millivoltmeter supplied with the gauge tube. This, however, required the presence of two operators. To allow one-man operation, the probe output was fed through a selector switch to the millivolt recorder[5] used for

taking mass probe readings. Once this was done, one technician could make complete filter velocity traverses, the result being recorded as a series of peaks on the recorder strip chart. It is estimated that the cost of materials for the recording filter velocity probe, exclusive of recorder itself, is well below $100.

Calibration of the Probe

Data for a basic calibration curve for the filter velocity probe, millivolts vs. ft^3/min, were obtained through use of a wet test meter in series with the thermal anemometer gauge tube. The probe calibration curve, Figure 11, is then obtained by dividing the various volumetric flow rates by the effective open face area of the probe head (1.83 $in.^2$). An accurate volumetric flow rate to a given filter bag can be measured in the laboratory, this flow rate divided by the total surface area of the bag being the average filter velocity (filter ratio). The effective probe area is then determined by dividing the mean volumetric flow rate through the probe by this average filter velocity. The mean volumetric flow rate used above is the average of flow rates through the probe measured at specific points on the filter, the average being representative of the entire surface of the test filter bag.

Use of the Probe

In practice, the chart reading for zero flow through the probe is adjusted to a prescribed value by varying the alternating current to the anemometer with a precision potentiometer. After the correct zero-flow reading has been established, the probe, with discharge end still

closed, is placed gently against the bag surface at the first point of the desired profile. The probe is then opened for about two seconds, producing a square peak on the recorder chart. With discharge end again closed, the probe is moved to the second position and another two-second reading taken. Eleven-point profiles along the length of a 6-foot filter bag have been produced in this way in less than a minute. The data on the strip chart are converted to tabulated filter velocities and these values are subsequently plotted as shown in Figure 12. The expected inverse relationship between mass and filter velocity is demonstrated quite clearly by the corresponding mass and filter velocity profiles shown in this figure.

Accuracy of the Probe

Because the pressure drop through the probe is on the order of one percent of the pressure drop across the filter, and because the filter area effectively blocked by the foam rubber face on the probe is less than one or two percent of the total filter area (these factors tend to compensate for one another), the filter velocity through the local area being metered should be within at least a percent or so of the filter velocity when the probe is not present. Hence, the potential accuracy of the filter velocity probe is quite high. Variations in other factors, however, combine to increase the uncertainty of measurements with this probe. The emf generated by the sensing thermocouple, the response of the millivolt recorder, and the technique used by the operator in placing the probe against the bag all contribute to measurement error. The operator error is by far the most important. For filter velocities greater

than about one ft/min, operators can reproduce measurements within about 5 percent. Below 1 to 1.5 ft/min the absolute reading error appears to be roughly constant, thus making the percentage error increase as the velocity decreases. At 0.5 ft/min, errors of as much as 10 percent are to be expected. These personal errors in individual readings are apparently random in nature, however, since material balances on air flow into and out of a test filter bag (air flow out based on a relatively large number of filter velocity readings) check within two to three percent.

ACKNOWLEDGEMENTS

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Table 1. PROPERTIES OF POSSIBLE BETA SOURCES(1)(2)

Isotope	Half-life	Maximum Beta Energy (Mev)	Half-thickness in Aluminum (grains/ft^2)	Maximum Penetration (grains/ft^2)	Range of Significant Gamma Energies (Mev)
Co^{60}	5.27 y	0.31	122	1,140	1.17-1.33
Zn^{65}	250 d	0.32	127	1,170	1.12
Cs^{137}-Ba^{137m}	33 y	0.52	250	2,360	0.66
Ag^{110m}	270 d	0.53	257	2,430	0.12-1.52
Sb^{125}	2.7 y	0.62	318	3,070	0.11-0.64
Cs^{134}	2.3 y	0.65	341	3,220	0.56-0.74
Kr^{85}	9.4 y	0.70	377	3,540	
Cl^{36}	4.4×10^5 y	0.71	386	3,640	
Tl^{204}	3.5 y	0.76	422	3,930	
Pb^{210}-Bi^{210}	22 y	1.17	765	7,000	0.05
Eu^{152}, Eu^{154}	13 y, 16 y	1.90	1,545	12,800	0.09-1.40
Sr^{90} - Y^{90}	19.9 y	2.18	1,915	15,000	
U^{238}*	4.5×10^9 y	2.32	2,090	16,300	0.05
Ce^{144}-Pr^{144}	282 d	2.97	3,070	21,000	0.13
Ru^{106}-Rh^{106}	1.0 y	3.53	4,075	25,400	0.51-2.41

*$U^{238} \xrightarrow{\alpha} Th^{234} \xrightarrow{\beta} Pa^{234} \xrightarrow{\beta} U^{234}$

BIBLIOGRAPHY

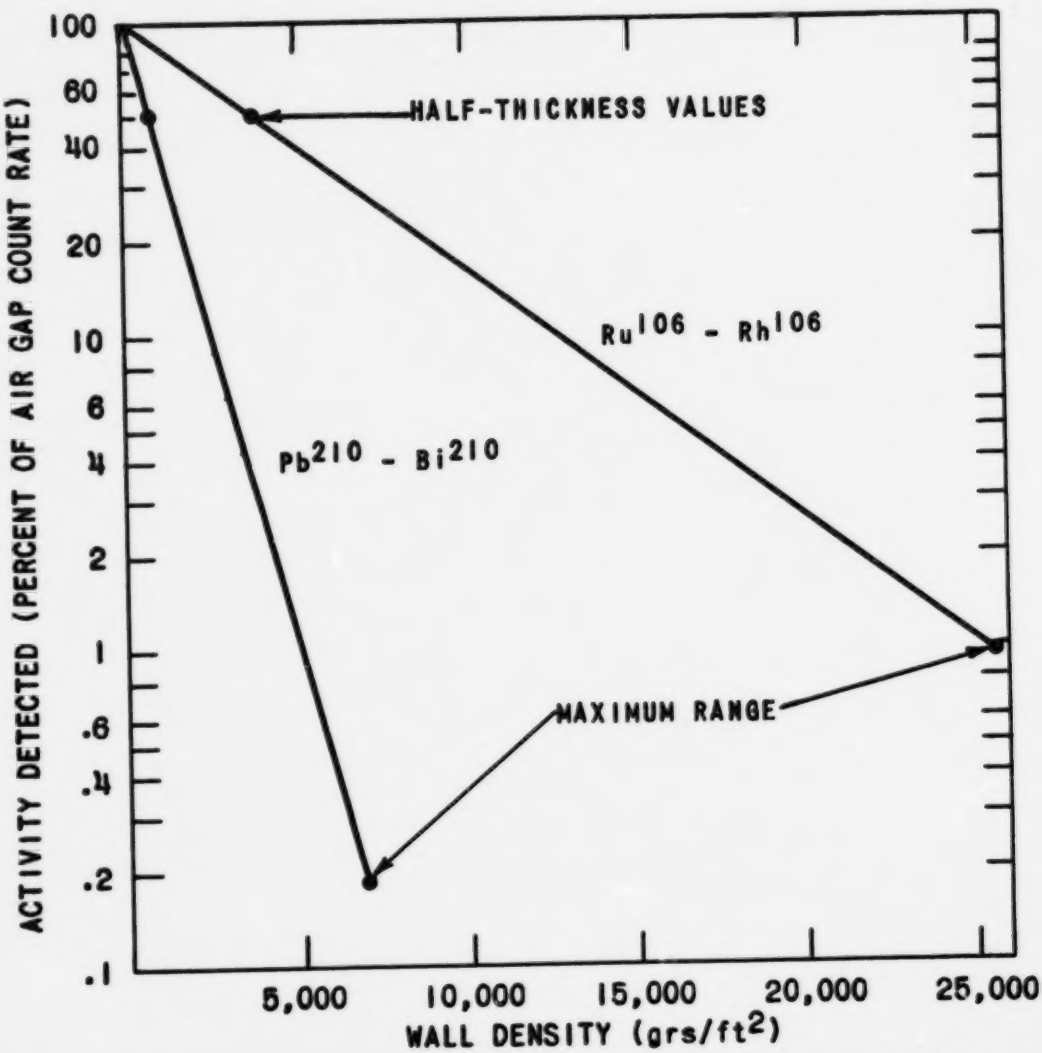
1. Radiological Health Handbook, Kinsman, Simon, ed., 92-3, U. S. Public Health Service, Cincinnati, Ohio, 1957.

2. Data from Analytical Chemistry Division, Oak Ridge National Laboratories.

3. Anger, H. O., "New Type Counting-Rate Recorder," Nucleonics, 8, n.2, 76-9, February 1951.

4. Glendenin, L. E., "Determination of the Energy of Beta Particles and Photons by Absorption," Nucleonics, 2, 12, January 1948.

5. Rose, A. H., Jr., Stenburg, R. L., Corn, M., Morsley, R. R., Allen, D. R., and Kolp, P. W., "Air Pollution Effects of Firing Practices and Combustion Air Distribution on Incinerator Operation," to be presented at 51st Annual Meeting, A.P.C.A., Philadelphia, Pennsylvania, May 26, 1958.



THEORETICAL CALIBRATION CURVES BASED ON HALF-THICKNESS VALUES

Figure 1

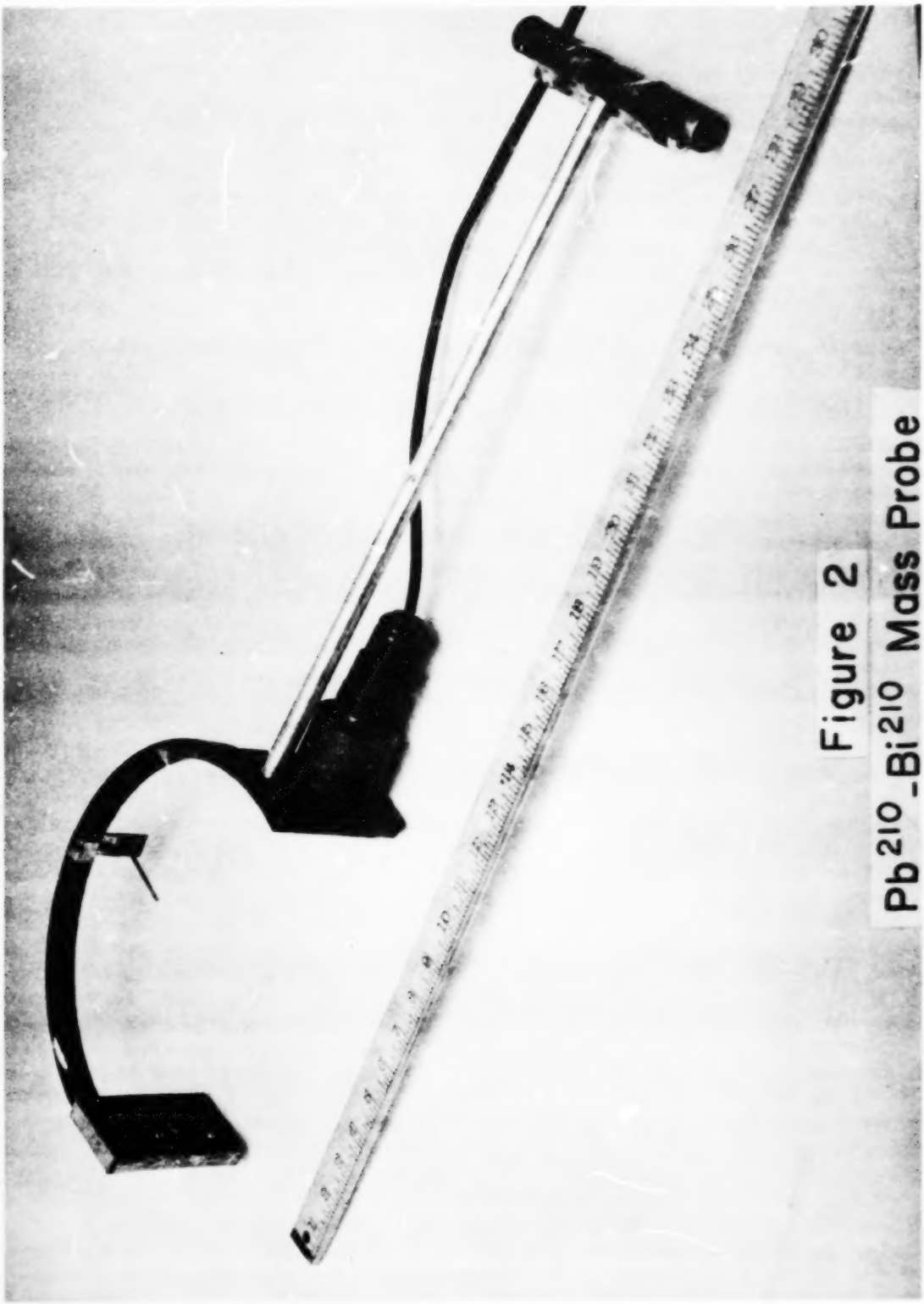


Figure 2

Pb^{210}-Bi^{210} Mass Probe

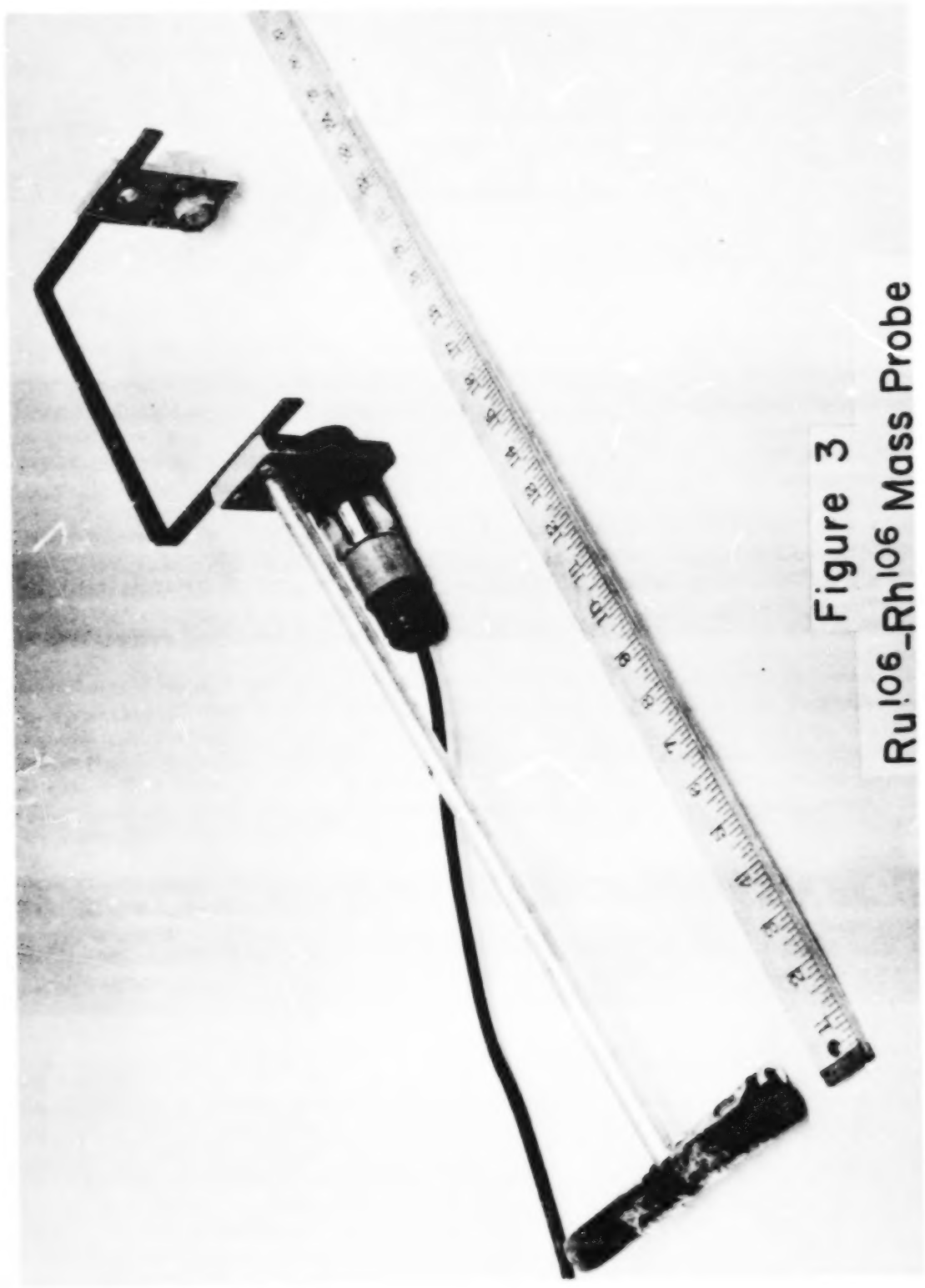
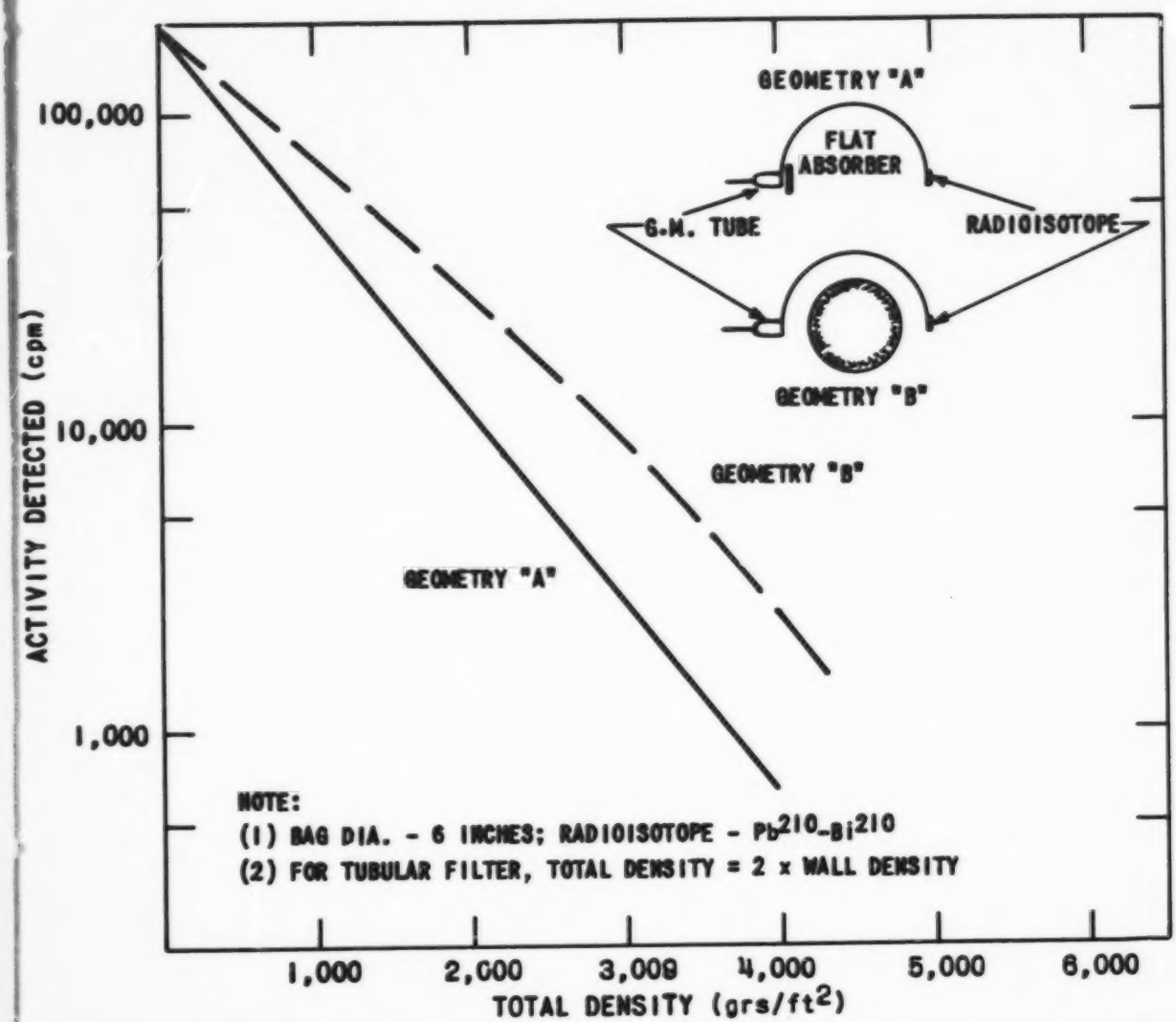


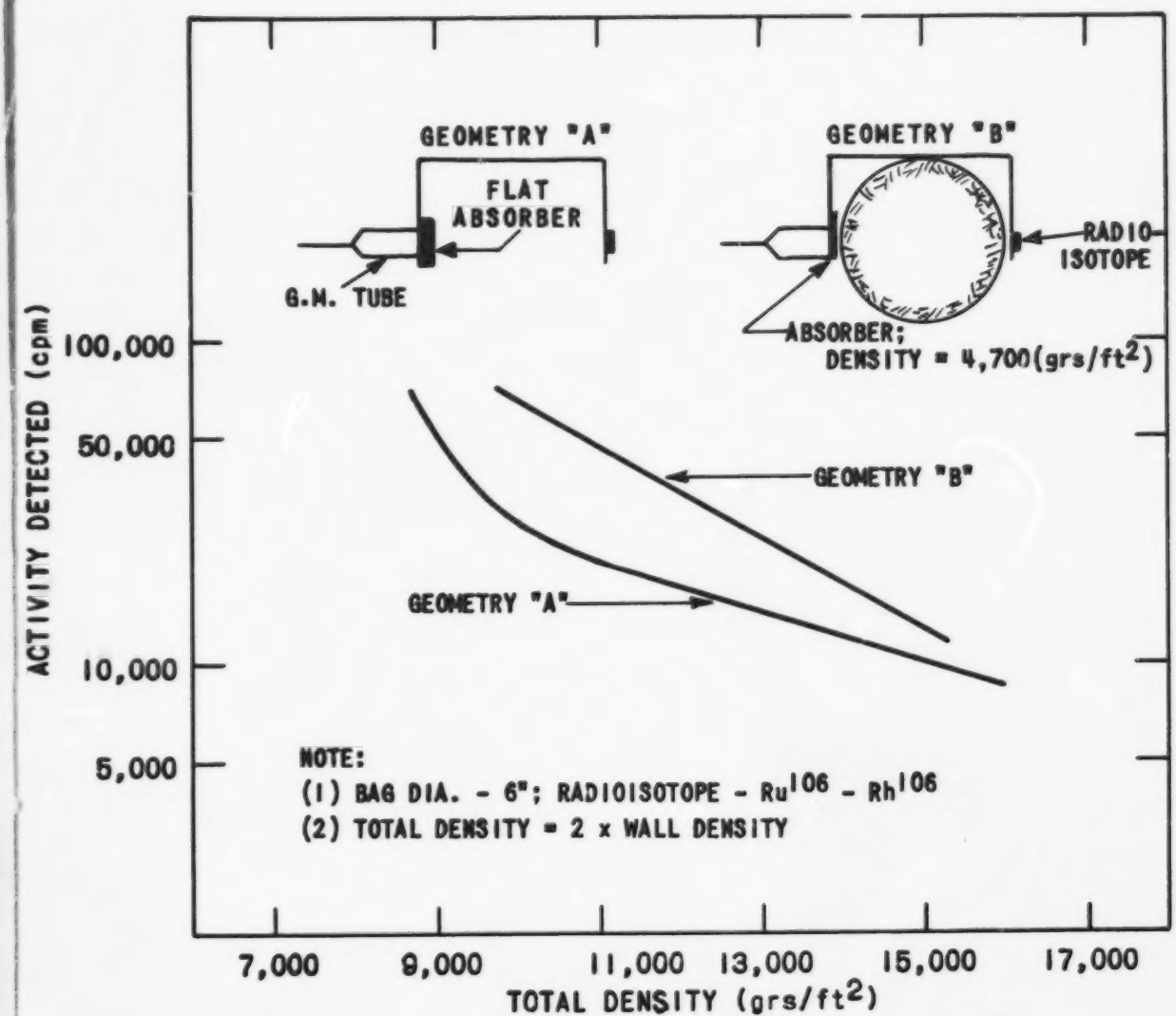
Figure 3

Ru^{106}-Rh^{106} Mass Probe



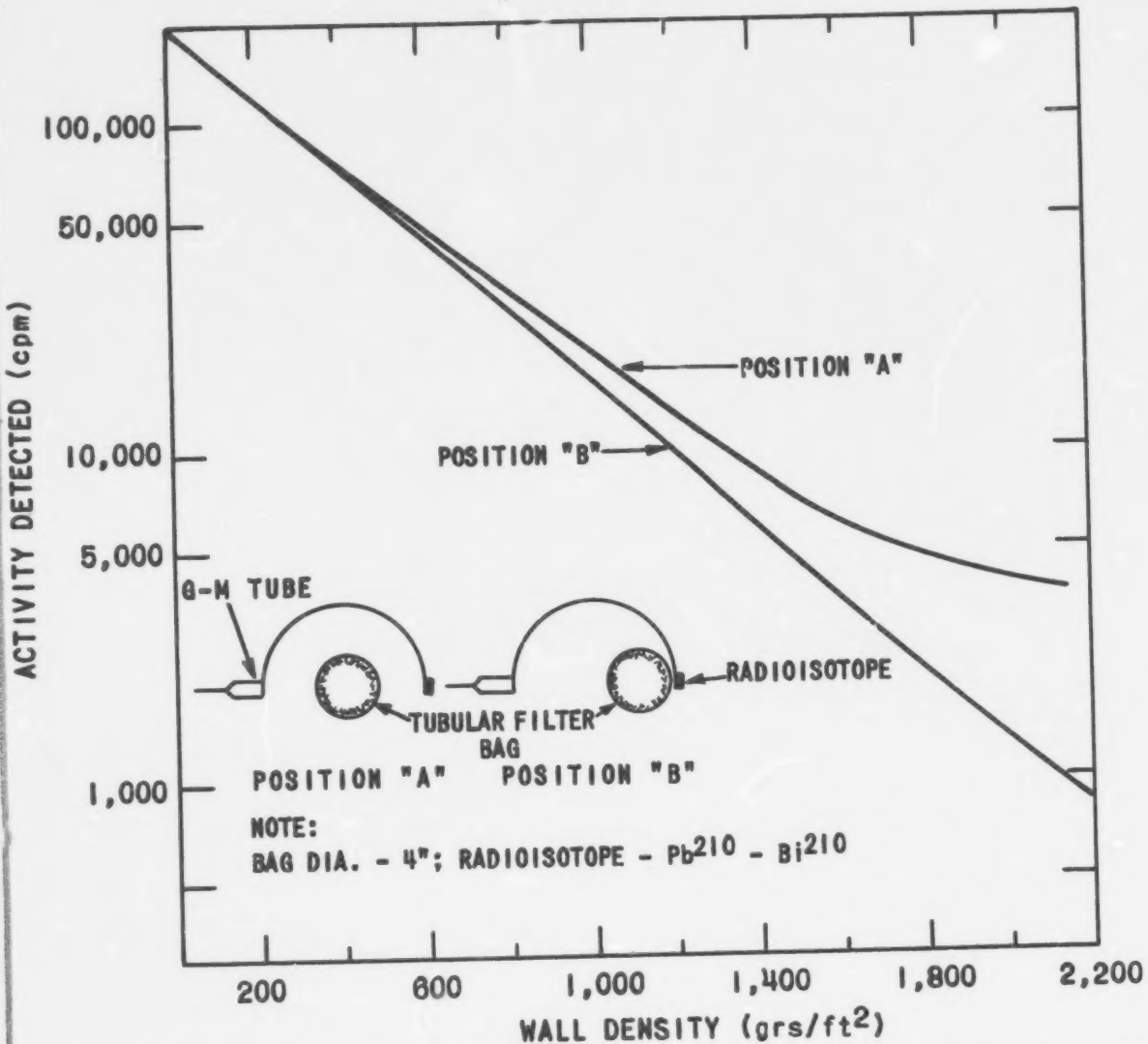
EFFECT OF ABSORBER GEOMETRY ON Pb^{210} - Bi^{210} CALIBRATION CURVE

Figure 4a



EFFECT OF ABSORBER GEOMETRY ON Ru^{106} - Rh^{106} CALIBRATION CURVE

Figure 4b



EFFECT OF PROBE POSITION ON CALIBRATION CURVE

Figure 5

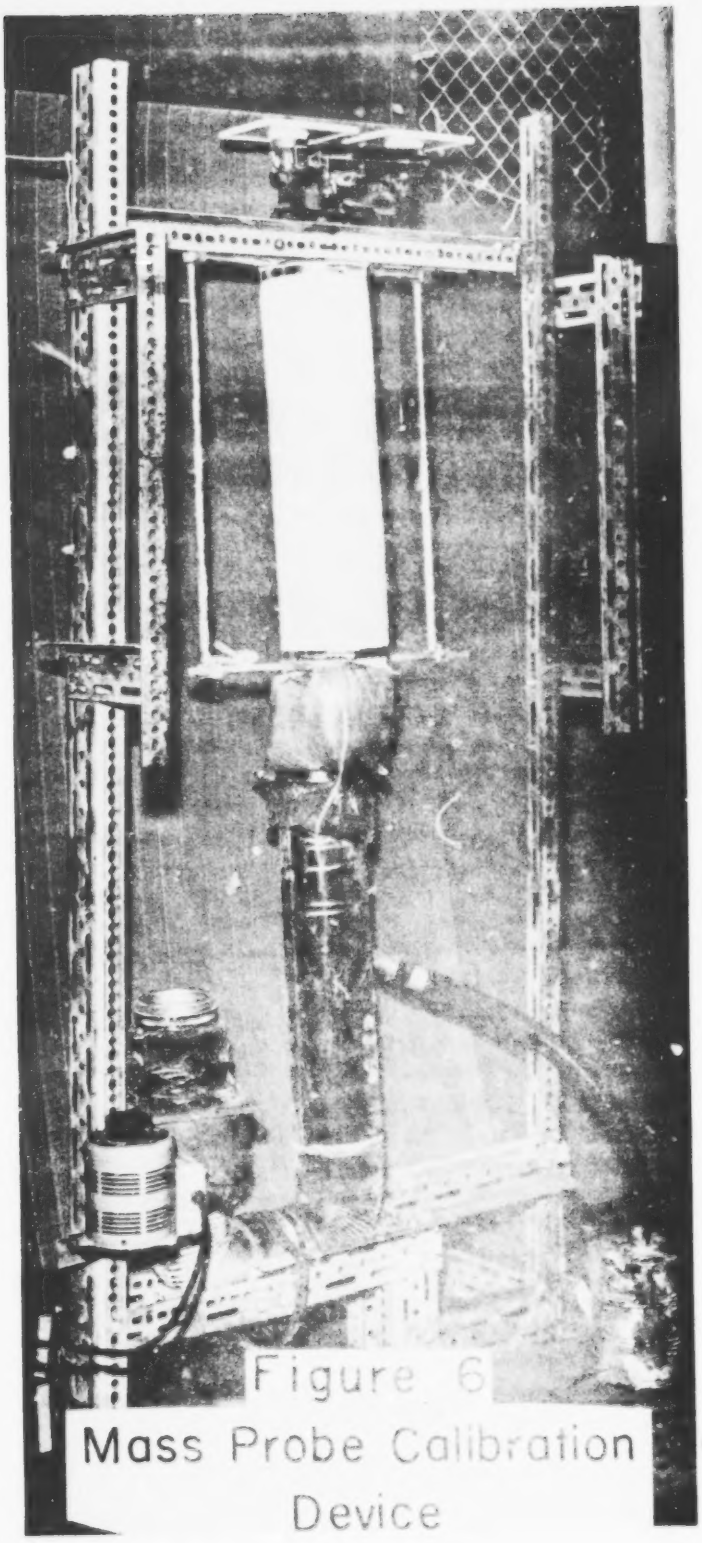
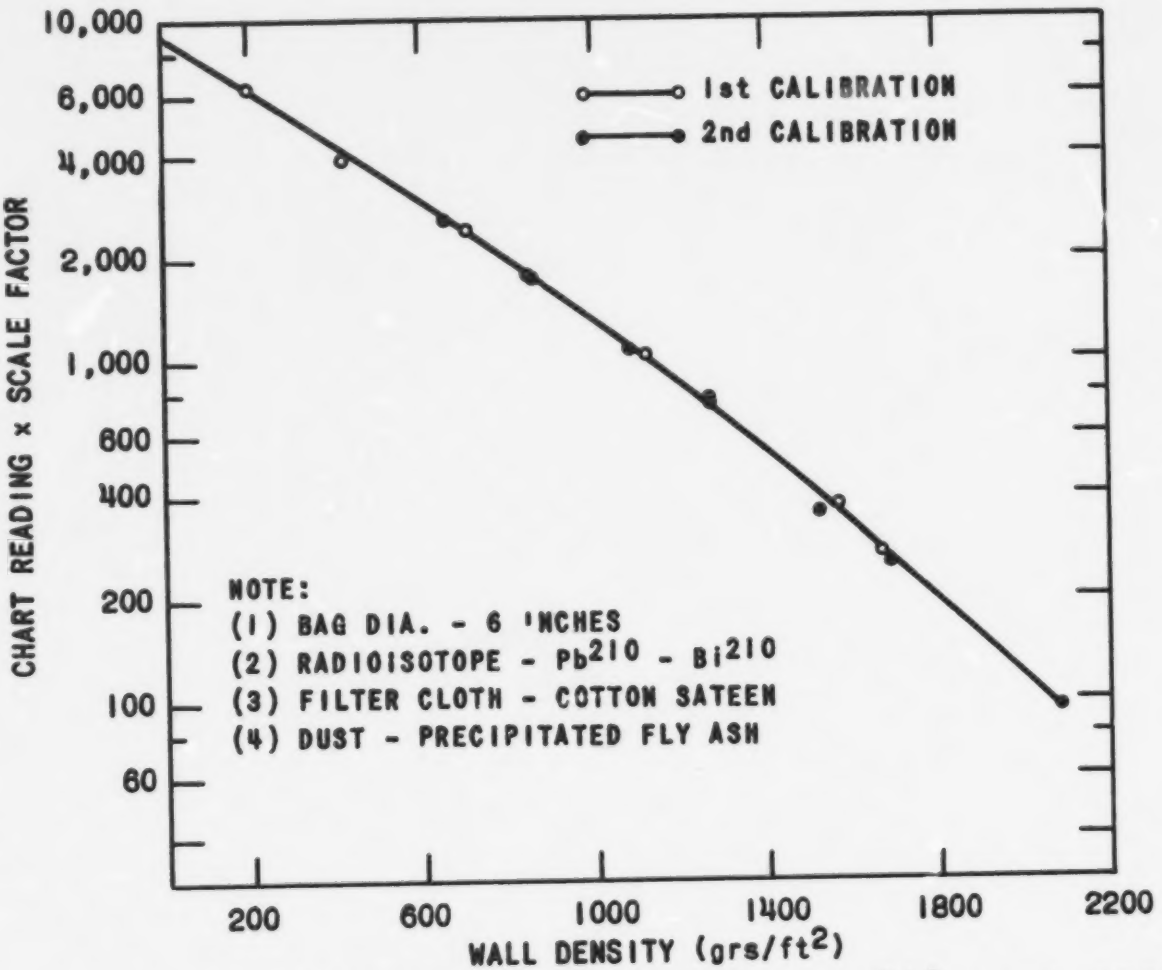


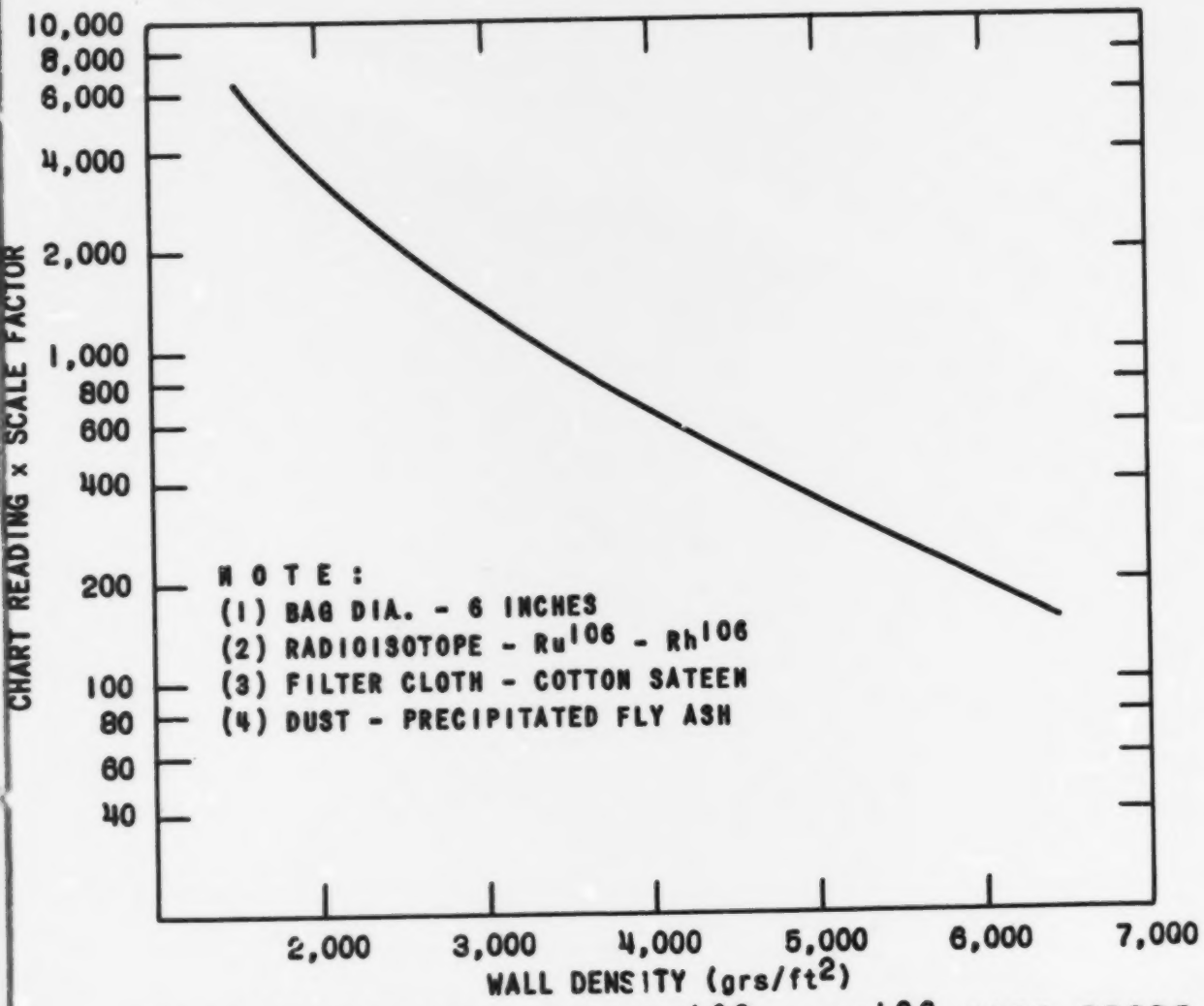
Figure 6

Mass Probe Calibration Device



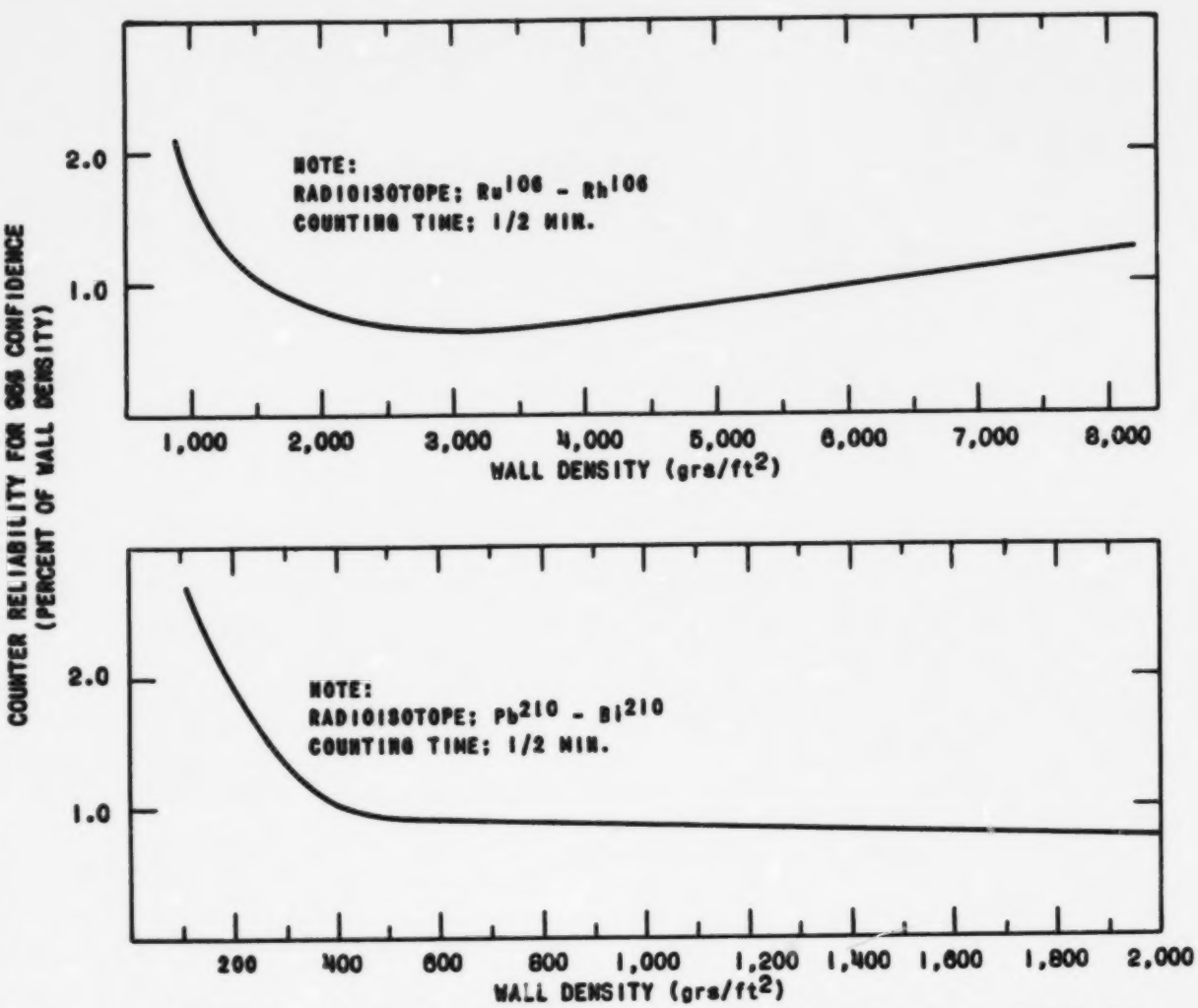
CALIBRATION CURVE FOR Pb^{210} - Bi^{210} MASS PROBE

Figure 7a



CALIBRATION CURVE FOR Ru^{106} - Rh^{106} MASS PROBE

Figure 7b



RELATION BETWEEN COUNTER RELIABILITY AND WALL DENSITY FOR Pb^{210} - Bi^{210} & Ru^{106} - Rh^{106} MASS PROBES

Figure 8

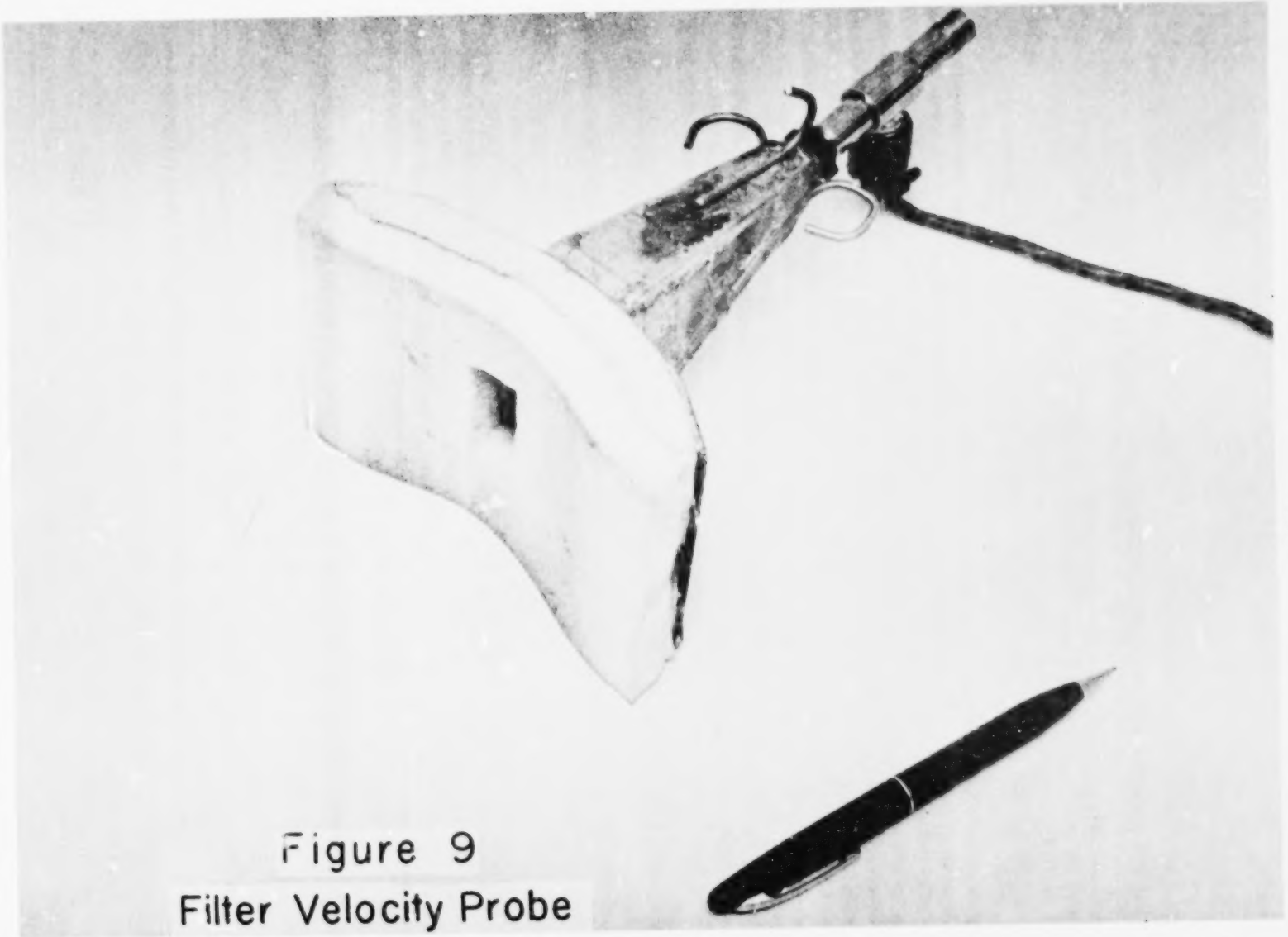
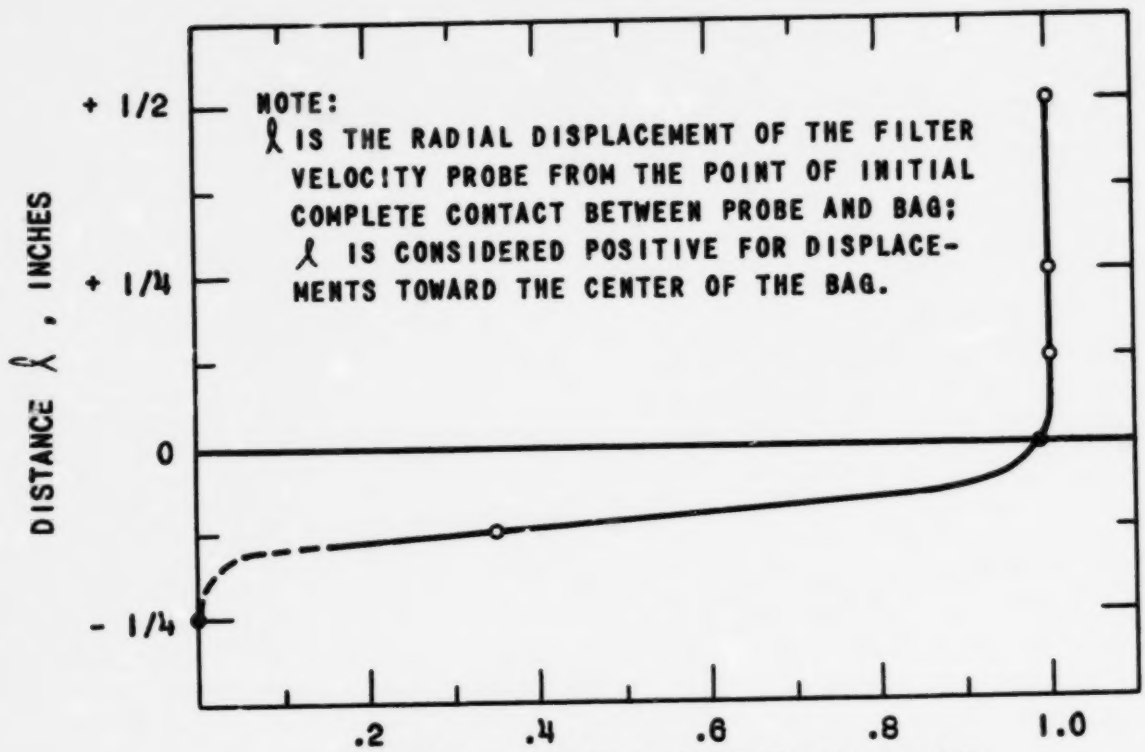
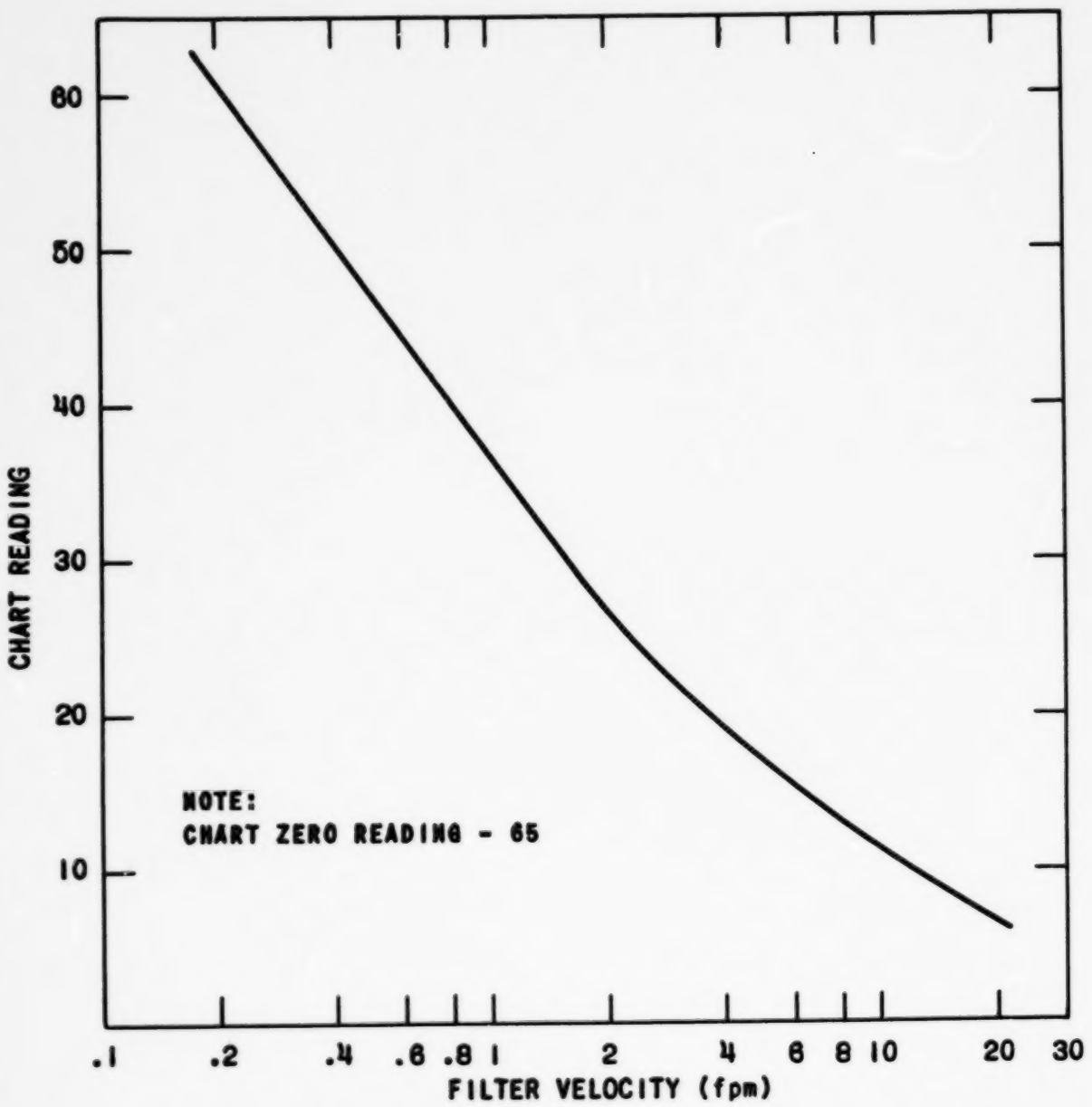


Figure 9
Filter Velocity Probe


NOTE:
ℓ IS THE RADIAL DISPLACEMENT OF THE FILTER VELOCITY PROBE FROM THE POINT OF INITIAL COMPLETE CONTACT BETWEEN PROBE AND BAG; ℓ IS CONSIDERED POSITIVE FOR DISPLACEMENTS TOWARD THE CENTER OF THE BAG.
+ 1/2
+ 1/4
0
- 1/4
DISTANCE ℓ, INCHES
.2
.4
.6
.8
1.0
MEASURED VELOCITY, FRACTION OF MAXIMUM

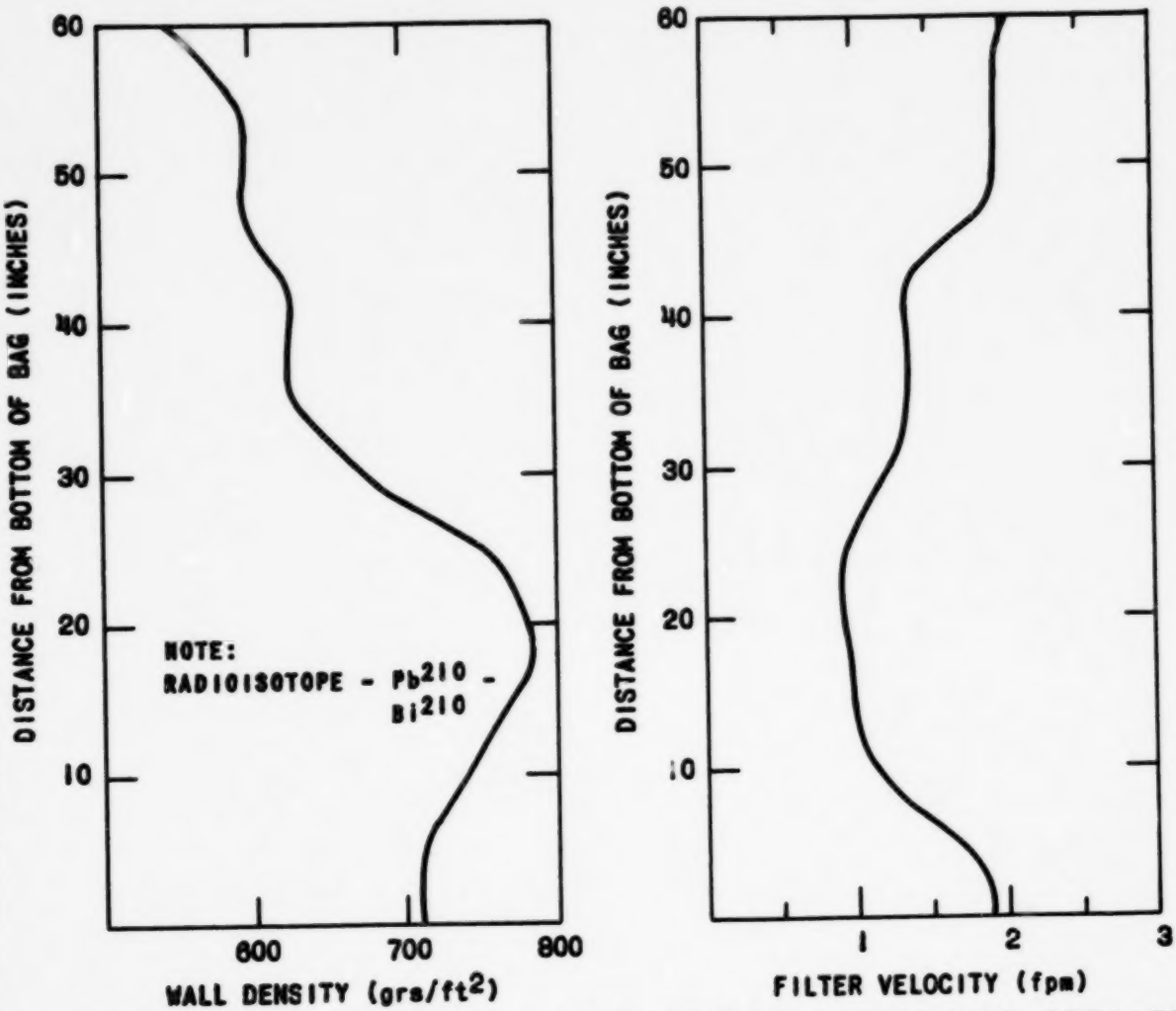
EFFECT OF PROBE POSITION ON MEASURED FILTER VELOCITY

Figure 10



CALIBRATION CURVE FOR FILTER VELOCITY PROBE

Figure 11



CORRESPONDING MASS & FILTER VELOCITY PROFILES OBTAINED WITH INSTRUMENTS DEVELOPED

Figure 12